

# V2 Scaling in PbPb Collisions at 2.76 TeV

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We investigate scaling properties of the elliptical flow parameter  $v_2$  in PbPb Collisions at 2.76 TeV within a recently introduced new theoretical scheme which accounts for hydrodynamically expanding bulk matter, jets, and the interaction between the two.

The transverse momentum ( $p_t$ ) dependence of the elliptical flow parameter  $v_2$  for identified hadrons has been investigated in great detail in heavy ion collisions at 200 GeV. A mass splitting has been observed at low  $p_t$ : the proton curve for example is shifted to the right compared to the pions, whereas at higher  $p_t$  the curves cross, the proton result finally being 50 % above the pion one. If one plots  $v_2/n_q$  versus  $KE_t/n_q$  (with  $n_q$  being the number of quarks of the hadron and  $KE_t$  the transverse kinetic energy) one observes a unique curve for many hadron species, referred to as quark number scaling. This is usually considered to support the idea of quark coalescence [1–4]. However, as shown in [5], the situation is more complex: scaling is observed in central AuAu collisions at 200 GeV, whereas in more peripheral collisions the scaling is broken for  $KE_t > 0.7\text{ GeV}$ .

In ref. [6], we introduced a new theoretical scheme which accounts for hydrodynamically expanding bulk matter, jets, and the interaction between the two. The whole transverse momentum range is covered, from very low to very high  $p_t$ . In [6], we show that the new approach can accommodate spectra of jets with  $p_t$  up to 200 GeV/c in  $pp$  scattering at 7 TeV, as well as particle yields and harmonic flows with  $p_t$  between 0 and 20 GeV/c in PbPb collisions at 2.76 TeV. Since our aim is a single model which is able to cover all phenomena, we will apply the approach of ref. [6], with exactly the same parameters (EPOS2.17v3), to study the question of scaling (or not) in PbPb collisions at 2.76 TeV.

The starting point of the new approach are color flux tubes which appear as a consequence of hard scatterings. In heavy ion collisions, we have many of these flux tubes, which constitute eventually both bulk matter (which thermalizes, flows, hadronizes, and finally performs hadronic scatterings) and jets, according to some criteria based on partonic energy loss.

The flux tubes are treated as kinky strings, where the kinks amount to transversely moving string pieces carrying the transverse momenta of the hard partons. Three possibilities occur: (A) String segments which have not sufficient energy to escape will constitute matter, they lose their character as individual strings. This matter will evolve hydrodynamically and finally hadronizes (“soft hadrons”). (B) String segments having sufficient energy to escape and being formed outside the matter, constitute jets (“jet-hadrons”). (C) There are finally also

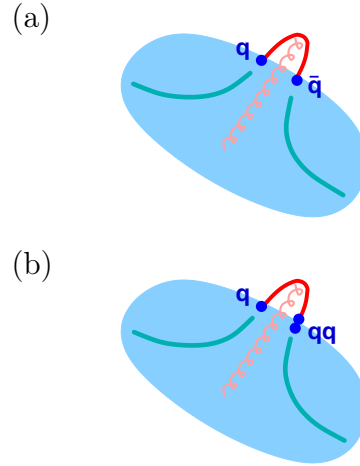


Figure 1: (Color online) Escaping string segment, getting its endpoint partons from the fluid. We show the case of a quark and an antiquark (a) and of a quark and a diquark (b). The rest of the string dissolves in matter.

string segments produced inside matter or at the surface, but having enough energy to escape and show up as jets (“jet-hadrons”). They are affected by the flowing matter (“fluid-jet interaction”).

Interesting is case (C). The jet-hadrons are produced still inside matter or at the surface, but they escape. Here we assume that the quark, antiquark, diquark, or antidiquark needed for the flux tube breaking is provided by the fluid with properties (momentum, flavor) determined by the fluid rather than the Schwinger mechanism, whereas the rest of the string dissolves in matter, see fig. 1. Considering transverse fluid velocities up to  $0.7c$ , and thermal parton momentum distributions, one may get a “push” of a couple of GeV to be added to the transverse momentum of the string segment. Important for the discussion in this paper: baryons ( $n_q = 3$ ) are more pushed than mesons ( $n_q = 2$ ). This property is similar to the coalescence mechanism, but there is also a substantial difference: the sum of the transverse momenta of the  $n_q$  quarks is only a fraction of the total  $p_t$ , since an important contribution comes from the flux tube segment (carrying the parton  $p_t$ ). At large  $p_t$  the latter contribution

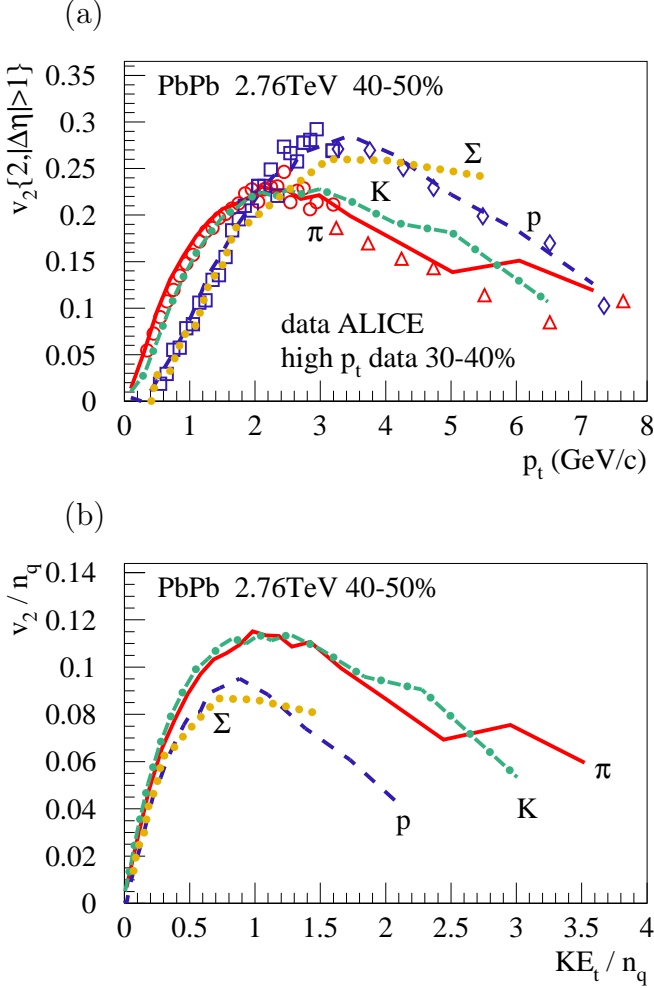


Figure 2: (Color online) (a) Transverse momentum dependence of  $v_2$  for pions (full line), kaons (dashed-dotted line), protons (dashed line), and sigma baryons (dotted line) in semi-peripheral PbPb collisions (40-50%) at 2.76 TeV. We also show pions (circles and triangles) and protons (squares and rhombi) from ALICE [7] (the high  $p_t$  data refer to 30-40%). (b) Scaling representation of the curves from (a).

dominates, quark number scaling will be violated.

In fig. 2(a), we show the transverse momentum dependence of  $v_2$  for pions (full line), kaons (dashed-dotted line), protons (dashed line), and sigma baryons (dotted line) in semi-peripheral PbPb collisions (40-50%) at 2.76 TeV. We also show pions (circles and triangles) and protons (squares and rhombi) from ALICE [7] (the high  $p_t$  data refer to 30-40%). We clearly see the mass splitting at low  $p_t$  and crossings at higher  $p_t$ . In fig. 2(b), we plot the four curves as  $v_2/n_q$  versus  $KE_t/n_q$  (scaling representation). Whereas we see scaling at small  $KE_t$ , at high  $KE_t$  the mesons and baryons separate (scaling violation), which is at least very clear for the protons, for

the sigma baryons we are limited to relatively small  $p_t$ , due to statistics.

To understand the effect of hadronic final state rescattering, we plot in fig. 3 the corresponding curves for the calculations without cascade. As expected (from RHIC), at low  $p_t$  there is much less mass splitting, and consequently there is no scaling. So the low  $KE_t$  scaling is a hadronic effect (maybe due to the fact that  $MN$  cross sections are roughly 2/3 of  $BN$  cross sections ( $B$  being a baryon,  $M$  a meson,  $N$  a nucleon)). At high  $KE_t$ , the results are similar to the ones from the full calculation.

To summarize: We predict scaling only for small values of  $KE_t$ , at larger values the scaling is violated, clearly seen for the protons. We attribute this to the fact that with increasing  $p_t$  the deviation of our approach from simple coalescence increases.

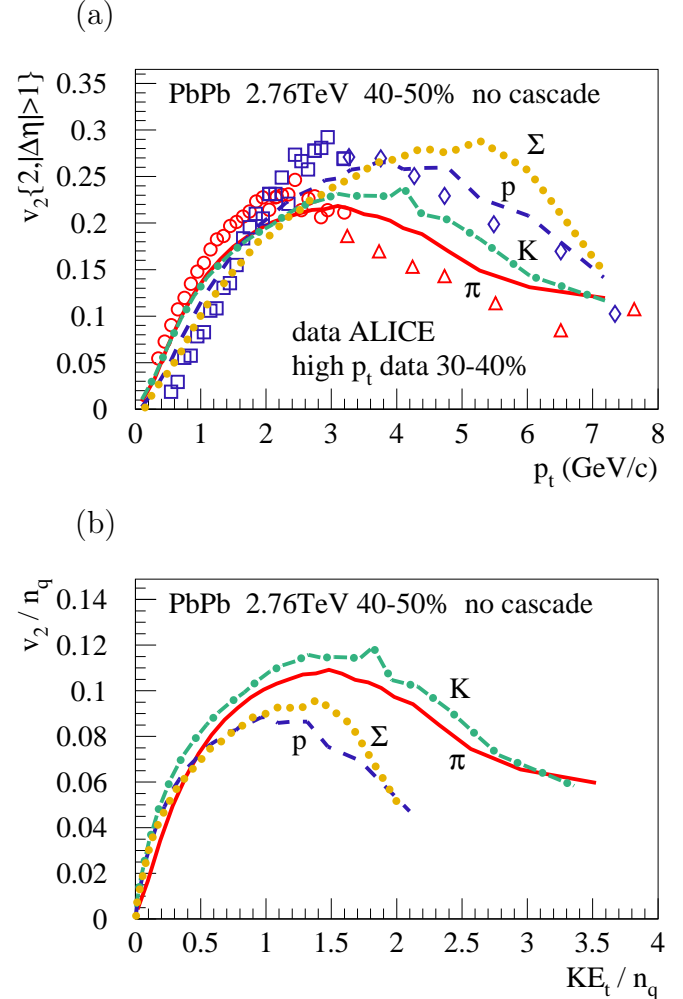


Figure 3: (Color online) Same as fig. 2, but calculation without hadronic cascade.

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